Disclosure Evaluation Team
IPE Invention Evaluation Report

Disclosure Number: <u>01-157</u> **Invention Title:** ASSET Electrical Power Generation and Distribution System Method

Inventors:

Bond, Robert M.

Flag Date: 01-May-2001 **Reason:** 4/20/01 Submittal for best paper.

5/1/01 200 copies mailed and transmit an electronic copy

5/21/01 30 minute presentation on paper at conference in afternoon.

Reportable Invention:

Technology Codes:

P PAA Airplane Development Processes

Product Codes:

P a Commercial Airplanes

IP Engineer: REM **IPE Recommended DEC Rating:** 1

Recommended Protection: Patent

If Hold, Re-Evaluation Date (date questionnaire mailed):

DEC DECISIONS:

Assigned DEC Rating (1-5):

If Defer: Meritorious Invention Award? (Yes/No):

Filing Decision Rating: .... ***Filing Decision Date:*** ....

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Disclosure Number: 01-157 **Invention Title:** ASSET Electrical Power Generation and Distribution System Method

Invention Disclosure:

Introduction

It is important to be able to influence the design of aircraft subsystems in the definition phase. This makes it possible to influence weight at a lower cost than is possible in the design or production phases. Invented is a method that synthesizes an approximate part-level design from a combination of airplane level configuration data, fundamental engineering theory, cross-functional design/analysis practices, and refinement of results as more detailed, real data becomes available. Automated knowledge based engineering (KBE) up front provides the initial characterization of the design.

For example, electrical power generation and distribution system designs are evaluated from five viewpoints. These are weight, body station center of gravity, dependability cost, reliability, and maintainability. Calculation of multiple attributes allows rapid trade study capability using a variety of measures. This cuts cycle time in the risk assessment process.

Sizing generation-associated components relies upon data extracted from the loads and architecture modules. The load module dictates the required capacities and the architecture module specifies the quantities of the various components.

Feeder wire sizing involves determination of feeder heating effects as a function of current, altitude, ambient temperature of the feeder's location, wire type, and bundle configuration derating. System voltage distortion due to harmonics is estimated as a function of frequency.

Background:

Current parametric/statistical weight analysis methods are grossly inadequate in ensuring weight efficiency and weight compliance of aerospace products. These methods produce estimates with large, unexplainable tolerances and are insensitive to key design parameters, precluding the ability to adequately discriminate between design variations or perform rapid trade studies. This makes early, effective weight control and design guidance difficult and increases the cycle time for design convergence. Consequently, weight growth occurs during detail design, often requiring costly rework and weight reduction programs. It also results in heavier than necessary aircraft empty weights, affecting the competitiveness of the products, thereby negatively impacting sales.

Normally many factors are considered in a decision making process. For example, consider all the things a residential home purchase involves. Seldom does an ideal home present itself. Alternative electrical systems also have many pluses and minuses.

Some important trade factors, such as reliability, maintainability, or dependability cost have historically been done by other disciplines. Quick assessments of this suite of measures, in addition to mass properties, can be useful to the enterprise as a whole. The method brings attention to areas of concern that can then be investigated by specialists.

INVENTION: ASSET is a set of knowledge-based, design approximation tools. These tools produce sufficient design detail to (1) calculate a component's weight (and cost, reliability, etc.), through simple calculation, and (2) do multi-level trade studies.

ASSET tools are designed to execute with as few as a handful of configuration parameters. It is also designed to execute with almost any level of design or analysis parameters that have been established by the design team.

ASSET is a design approximation and weight assessment concept. It facilitates early, rapid, definitive weight determination and control at any stage in the product definition cycle, with particular emphasis on concept and preliminary design. It can facilitate early and rapid cost determination and control, and provide information on other design attributes such as reliability,

maintainability, and dependability cost.

When different design tools are used in the various design phases, one often experiences unexplained discontinuities caused by switching methods. ASSET methods are usable in all design phases.

ASSET is intended to provide detailed design and weight data, essentially on day one of a new program. It continues to enhance the design and weight data throughout the design cycle until the program is producing elements that can be directly weighed or precisely calculated.

A guiding principal is to replace the estimates with known data as it becomes available. If better knowledge of any of the hundreds of parameters exists, the user overrides those values calculated by the method and locks them in. Inserting known, accurate values improves the accuracy of downstream calculations. Once a parameter value is locked in, it cannot be washed out by upstream values. Wash out refers to the phenomena of the program changing downstream parameters with its calculated estimate. Locking in better values allows a user to incrementally improve the method's accuracy as it progresses through preliminary to the detailed design phase.

The tools executional order comprises the following steps: Concept (initial definition - usually a coordination memo); Conditions (systems level definitions - architectures - IE variable freq power,); Configuration (systems level definitions in further detail); Sub Assemblies & Line Replaceable Units. The tool uses a knowledge base " Electronic Data Dictionary " comprising Boeing tribal knowledge, engineering theory, algorithms and product component specifications to formulate its solutions.

This tool was originally developed to help weights engineers "nail" weight approximations during design iteration. However, since 1998, the tool has incorporated multiple knowledge bases that have expanded its utility to approximate reliability, maintainability and dependibility cost.

Technical Value Considerations:

Technical Validity, Feasibility and Practicality: In development.

Technical Maturity: This tool was originally developed to help weights engineers "nail" weight approximations during design iteration. However, since 1998, the tool has incorporated multiple knowledge bases that have expanded its utility to approximate reliability, maintainability and dependibility cost.

Planned Technical Development: Certain aspects of it are in use since 1998.

Degree of Technical Innovation: Medium

Technical Benefit Relative to Existing Approaches

Total Technical Value Rating: high

Business Value Considerations:

Likelihood of Implementation: The first aspect comprising weight calculations was invented in 1991 & has been in use since 1998 in the production of the thrust reverser.

Value to Boeing Processes: COST AVOIDANCE: Early visibility for weight, reliability & maintainability cost is important to avoid costly weight reduction programs. REDUCED CYCLE TIME

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Value to Boeing Customers: Lowers acquisition costs.

Value to Boeing Competitors and Suppliers: Supplier data integrated into knowledge based model.

Value to Boeing as a New Business Opportunity: N/A

Consistency with Portfolio Strategy: Business & Knowledge Based Engineering Process.

Licensing Revenue Potential: Competitive Advantage

Total Business Value: HIGH

Legal Value Considerations:

Provisional was filed to beat a publication & white paper presentation date.

Recommended Protection and Justification:

Justification:

3 Abstract

It is important to be able to influence the design of aircraft subsystems in the definition phase. This makes it possible to influence weight at a lower cost than is possible in the design or production phases. A method is described that synthesizes an approximate part-level design from a combination of airplane level configuration data, fundamental engineering theory, cross-functional design/analysis practices, and refinement of results as more detailed, real data becomes available. Automated knowledge based engineering (KBE) up front provides the initial characterization of the design.

For example, electrical power generation and distribution system designs are evaluated from five viewpoints. These are weight, body station center of gravity, dependability cost, reliability, and maintainability. Calculation of multiple attributes allows rapid trade study capability using a variety of measures. This cuts cycle time in the risk assessment process. This software tool is useful to both weights and electrical power system engineers.

Sizing generation-associated components relies upon data extracted from the loads and architecture modules. The load module dictates the required capacities and the architecture module specifies the quantities of the various components.

Feeder wire sizing involves determination of feeder heating effects as a function of current, altitude, ambient temperature of the feeder's location, wire type, and bundle configuration derating. System voltage distortion due to harmonics is estimated as a function of frequency.

The method is user friendly, robust, and documented in an understandable manner. Default values for all parameters are constructed from two inputs; number of engines and maximum take-off weight. An on-line help function is provided and includes a feature that displays all equations used in the calculations. Detailed weight and body station center of gravity reports are provided in several formats.

4 Discussion

A recurring challenge faced by the Weight Engineer is to provide good weight information early in the airplane design process. This is necessary in order to be able to influence the design at relatively low cost and when the opportunity to do so exists. This paper describes a process to achieve that desired goal.

Current parametric/statistical weight analysis methods are grossly inadequate in ensuring weight efficiency and weight compliance of aerospace products. These methods produce estimates with large, unexplainable tolerances and are insensitive to key design parameters, precluding the ability to adequately discriminate between design variations or perform rapid trade studies. This makes early, effective weight control and design guidance difficult and increases the cycle time for design convergence. Consequently, weight growth occurs during detail design, often requiring costly rework and weight reduction programs. It also

results in heavier than necessary aircraft empty weights, affecting the competitiveness of the products, thereby negatively impacting sales.

Normally many factors are considered in a decision making process. For example, consider all the things a residential home purchase involves. Seldom does an ideal home present itself. Alternative electrical systems also have many pluses and minuses.

Some important trade factors, such as reliability, maintainability, or dependability cost have historically been done by other disciplines. Quick assessments of this suite of measures, in addition to mass properties, can be useful to the enterprise as a whole. The method brings attention to areas of concern that can then be investigated by specialists.

The term 'ASSET' refers to a concept of using an integrated suite of knowledge-based tools to derive a relatively detailed design approximation from any level of overall vehicle definition. Knowing the design details, the weight of the system can then be derived through simple calculation. These tools provide flexible design alternatives that utilize knowledge based engineering algorithms and have multi-disciplinary acceptance and usage. They have common look input and navigation pages. The use of built-in interfaces with other programs and autonomous calculations preclude the user from needing expertise in all of the different disciplines that make up the method (e.g., reliability and wire sizing).

The Figure 1 below illustrates the benefits of early product definition. Notice that the earlier one can influence the design, the less costly it is.

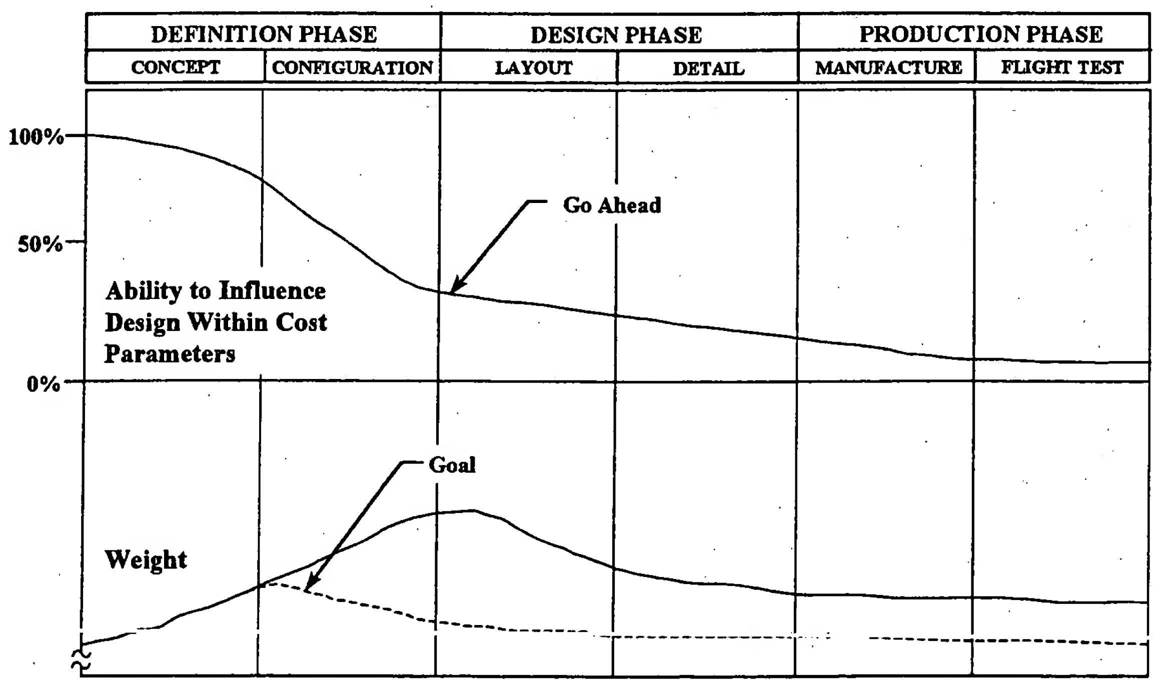

Figure 1: The Benefits of Early Product Definition

Once the transition from the design phase is made, it becomes increasingly costly to influence the design. Typically new airplane programs experience costly weight reduction programs that could have been avoided through the use of ASSET tools.

ASSET is a set of knowledge-based, design approximation tools. These tools produce sufficient design detail to (1) calculate a component's weight (and cost, reliability, etc.), through simple calculation, and (2) do multi-level trade studies.

ASSET tools are designed to execute with as few as a handful of configuration parameters. It is also designed to execute with almost any level of design or analysis parameters that have been established by the design team.

ASSET is a design approximation and weight assessment concept. It facilitates early, rapid, definitive weight determination and control at any stage in the product definition cycle, with particular emphasis on concept and preliminary design. It can facilitate early and rapid cost determination and control, and provide information on other design attributes such as reliability, maintainability, and dependability cost.

Figure 2 below illustrates the seamless nature of ASSET. When different design tools are used in the various design phases, one often experiences unexplained discontinuities caused by switching methods. ASSET methods are usable in all design phases.

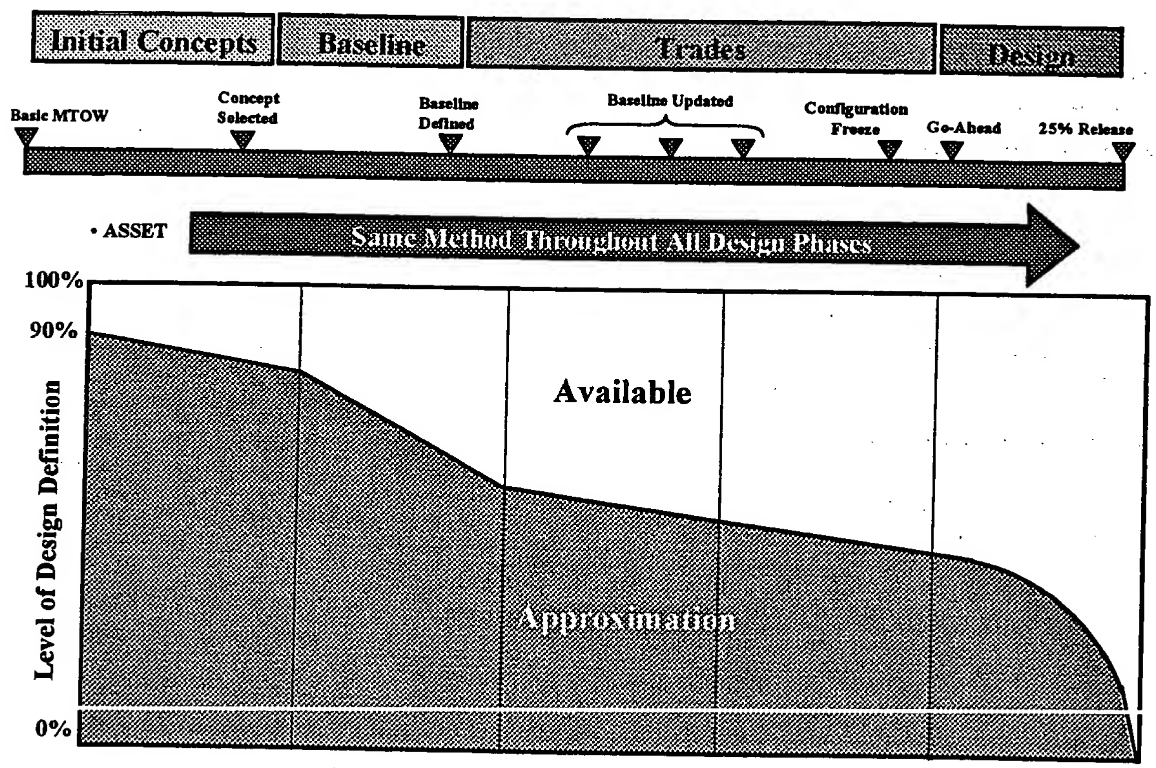

Figure 2: The Seamless Tool Characteristic

ASSET is intended to provide detailed design and weight data, essentially on day one of a new program. It continues to enhance the design and weight data throughout the design cycle until the program is producing elements that can be directly weighed or precisely calculated.

A guiding principal is to replace the estimates with known data as it becomes available. If better knowledge of any of the hundreds of parameters exists, the user overrides those values calculated by the method and locks them in. Inserting known, accurate values improves the accuracy of downstream calculations. Once a parameter value is locked in, it cannot be washed out by upstream values. Wash out refers to the phenomena of the program changing downstream parameters with its calculated estimate. Locking in better values allows a user to incrementally improve the method's accuracy as it progresses through preliminary to the detailed design phase.

The algorithms incorporated are applicable to all design phases. This permits seamless use through design phases from preliminary through detailed design, avoiding discontinuities caused by switching methods. Weight calculations proceed in a tumble-down manner (see Figure 3).

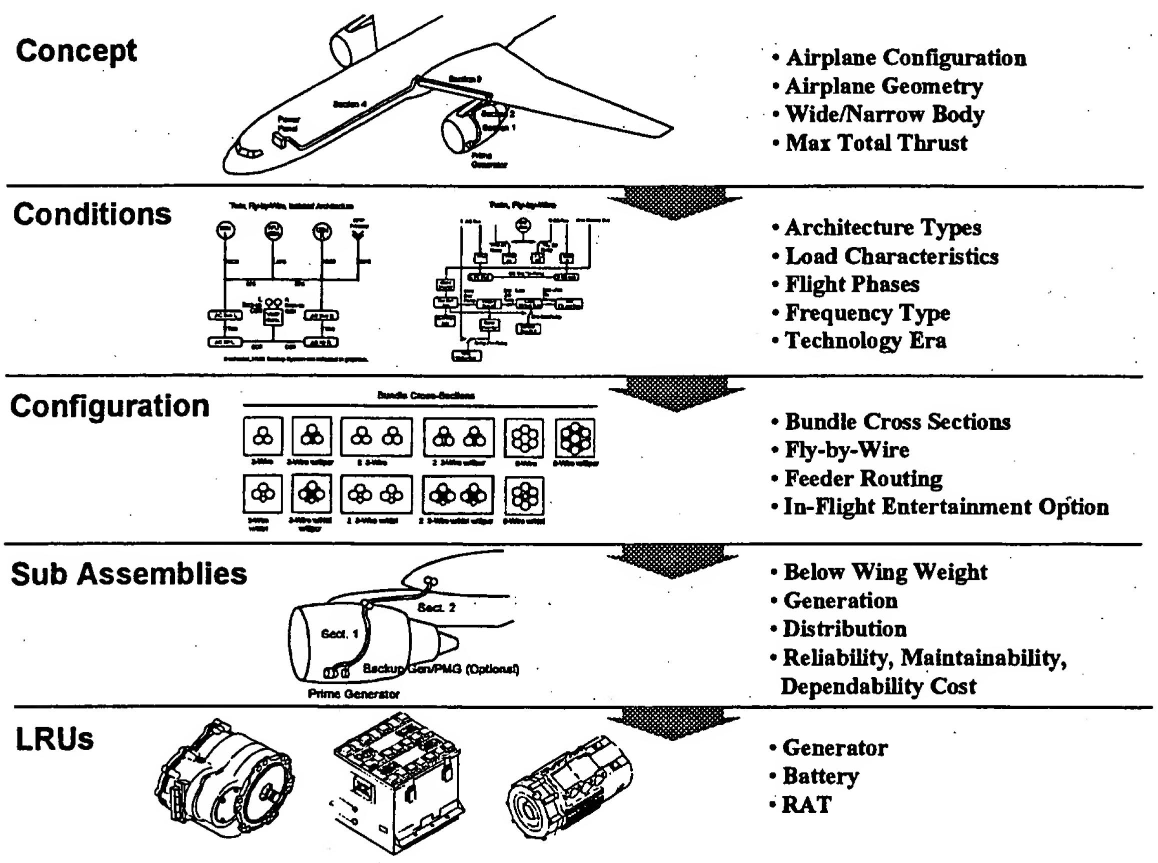

Figure 3: Tumble-Down to Detailed Weights

The general flow of the program is shown in Figure 4 below. Generation refers to the various generation components such as generators, generator control units, batteries, battery chargers, static inverters, power supply assemblies, regulated transformer rectifier units, and motor controllers. Distribution refers to the main power feeders on the aircraft and the distribution panels.

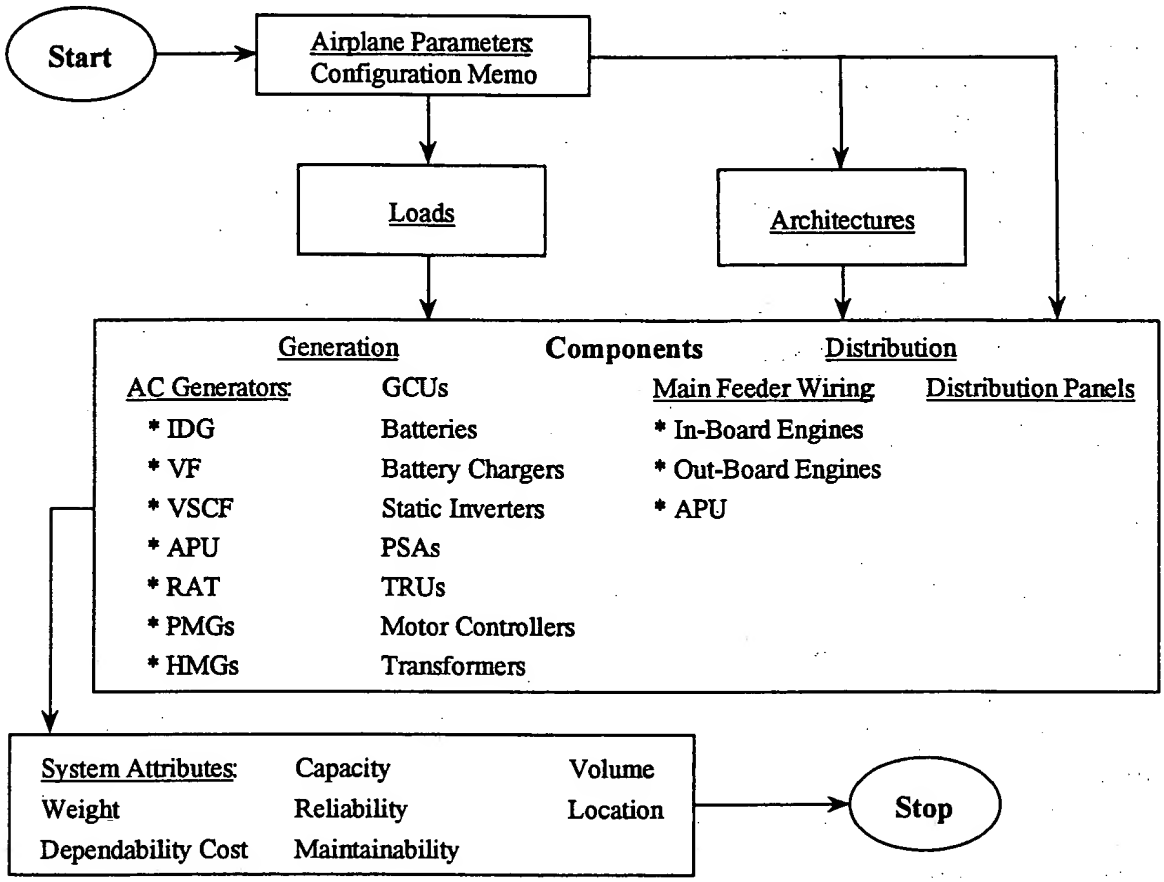

Figure 4: Computational Flow Diagram

A software functional specification provided a road map during method development. It defined the order of calculation of the variable names found in an on-line, computerized data dictionary. The software functional specification defines and illustrates each screen's layout. All variables, parameters, and formulas are completely specified and explained. The data dictionary is used in conjunction with the software functional specification to partially automate coding and compilation of the program.

Although the method only provides design-based weight analysis of electrical systems on commercial aircraft, it creates a paradigm that can be extended to other aerospace vehicles such as military aircraft, rotorcraft, or spacecraft. It supports product development activities associated with both new and derivative airplanes. Both twin and four engine aircraft are currently considered.

In general, the perspective used in building the method was that of an electrical power systems engineer rather than a mass properties engineer. Standard electrical design techniques were used to the greatest extent possible. Only after quantification of the system's electrical aspects were the system attributes of weight, reliability, maintainability, dependability cost, and body station center of gravity estimated.

The method makes it possible to do trades by comparing competing electrical system candidates from the several perspectives of the system attributes. The method is very fast when compared to conventional, manual techniques. Component selection is changeable by the user at various locations within the program. Many options can be traded.

5 Airplane Parameters

High level airplane parameters are usually found in configuration memos for new airplanes. It is usually possible to run the method with reasonable accuracy (usually within five to ten percent) with only two inputs normally found in a configuration memo. These required inputs to run the program are MTOW and number of engines (see Figure 5 below). Quick trades are possible without inputting a lot of data.

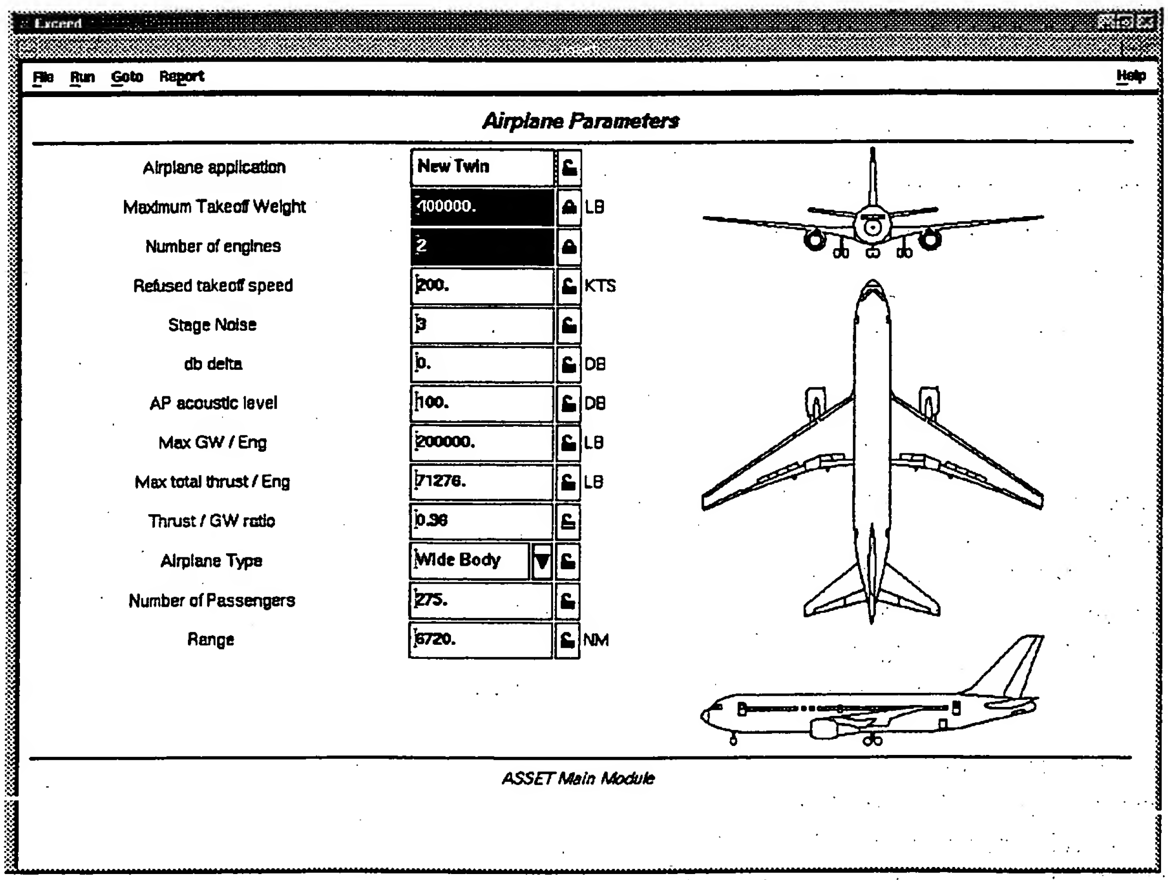

Figure 5: The Airplane Parameters screen

6 Electronic Data Dictionary

All engineering theory related to the method is documented in the data dictionary. The theory presentation in the form of data dictionary entry sequence is contained in the functional specification. The computer program implementing the method is generated directly from the data dictionary. Entries in all fields except the "Notes" field are incorporated into the computer code autonomously through a specialized compiler. Users, developers, and programmers collaborate for usability. The "Notes" field is free form for the engineer to pass information to the programmer that will be useful in coding. It is not necessary for the engineer to have detailed knowledge of the programming language.

Users and developers can review the theoretical equations and text explanations through a help function. By contacting the method developers, users can influence program evolution by requesting changes to data dictionary entries. It is possible to selectively sort data dictionary records (e.g., by Category and Level). In this way EPGDS records can be separated from other system categories. Matrices up to the third degree may be input. Figure 6 shows a typical data dictionary record.

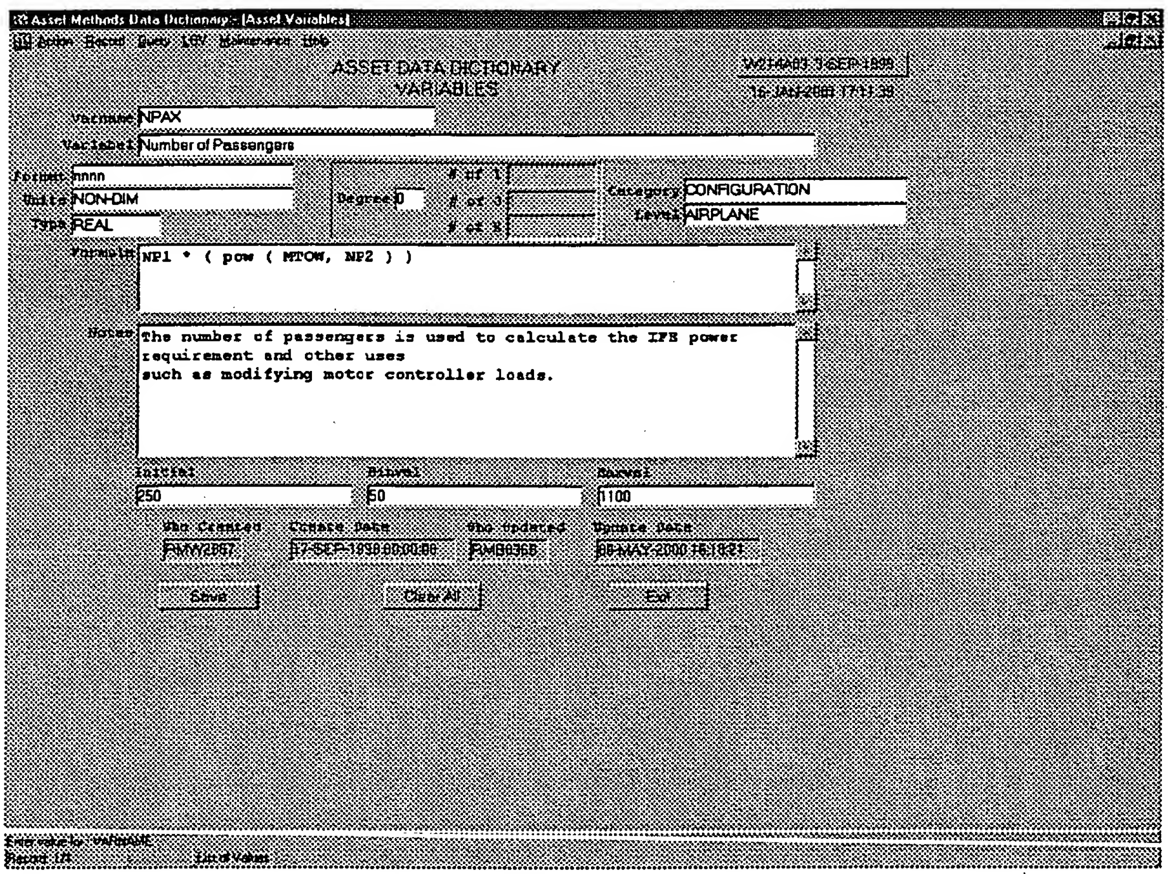

Figure 6: Data Dictionary Record

7 Configuration

This section characterizes the type of electrical system being used. A configuration screen is used for general parameters needed by the main modules, namely; loads, architecture, generation, distribution, and system attributes. These parameters include frequency type, technology era, fuselage length, fan diameter, wing span, and many others that define the airplane. Most of the configuration screen is concerned with the various aircraft geometry quantities.

Figure 7 below shows a portion of the configuration screen. Note that a scrolling device along the right border of the screen allows the user to control what is displayed on the screen.

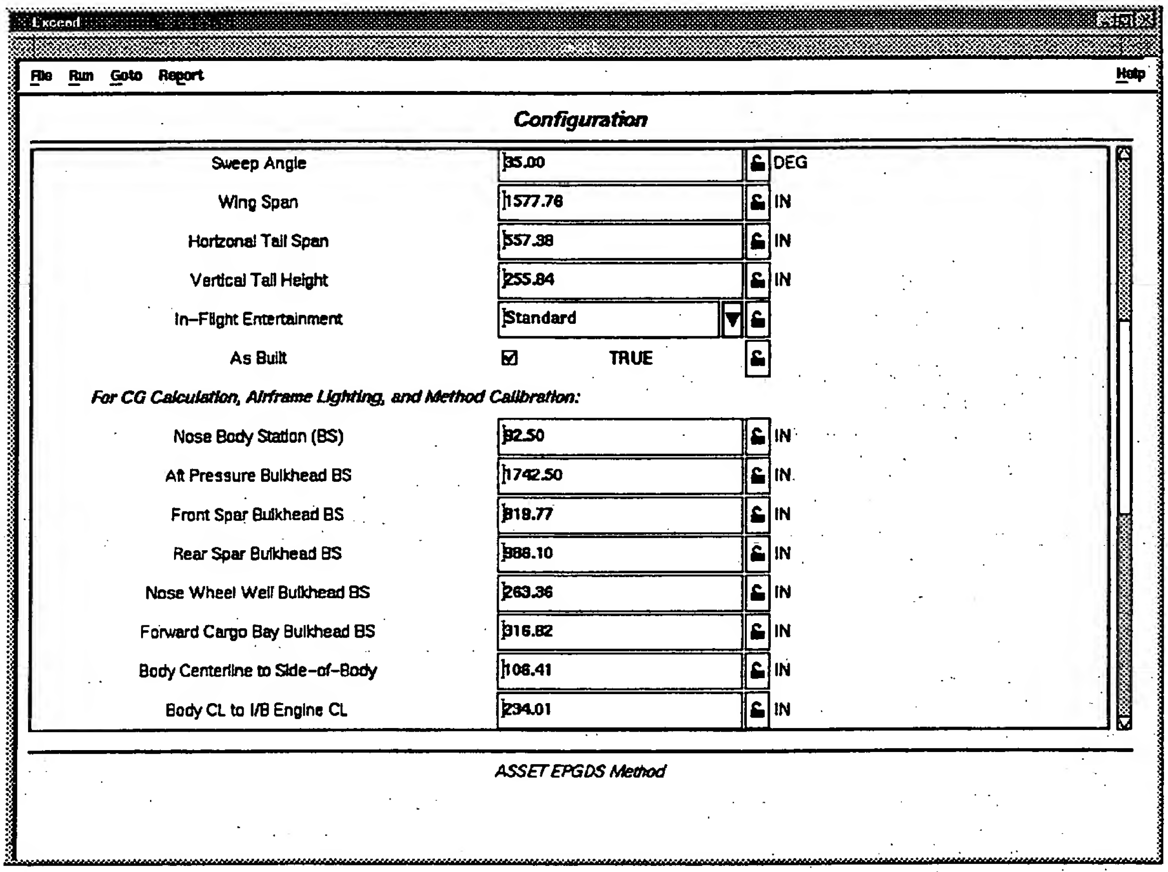

Figure 7: The Configuration Screen

All necessary geometry quantities are estimated by the method. If the user has a configuration memo or other defining document, these estimates should be overridden. This allows a more precise calculation for the body station center-of-gravity and feeder length. Automating this characterization process from a central database is being considered. Electronic transfer directly from a central, common source of configuration data would reduce the possibility of errors.

8 Loads Analysis

Special attention is paid to loads analysis. Electrical loads drive the component capacity ratings and the gauges of the power feeders. The load analysis is split into five major parts; full alternating current (AC) load analysis, essential AC loads, direct current (DC) loads, standby DC loads, and in-flight entertainment (IFE) loads. The method was coded in C/Motif, but the loads analysis was first implemented in an Excel workbook. This allowed verification of the method's results by comparison with the Excel workbook.. It was also verified by running the method against existing aircraft with known loads.

Six major flight phases are considered. These are passenger loading, engine start, taxi out, takeoff & climb, cruise, and descent & land. The flight phase with the greatest summed load is determined by comparison with the others. That load establishes the largest AC or DC load required. The load summations for the other flight phases are discarded for generation and distribution component sizing purposes. The power factor, which relates resistive and inductive components of the loads, is used in AC calculations to improve accuracy over a purely scalar calculation.

In-flight entertainment power requirements are calculated due to their high power consumption and the current industry interest in this feature. The user can switch between standard or elaborate systems. The default value depends on the size of the aircraft. Small aircraft on short routes tend to have less exotic in-flight entertainment systems than long range twins or large quads.

The most probable electrical loads and weights of some components vary depending upon the epoch of the system. Two options are allowed by the method. These are "current year" and "2005". This allows estimates based on the time of program kickoff. For those of you mathematically inclined, this might be an area for the application of a Kalman filter.

9 Architecture

A variety of electrical architectures are investigated and populated with appropriate components. Four typical electrical power system architectures covering quads and twins are included. These are quad fly-by-wire, quad non fly-by-wire, twin fly-by-wire, and twin non fly-by-wire. These are illustrated on screens by one line electrical diagrams. The systems illustrated in architecture sets are Main/Backup AC System, DC/Standby System, Flight Control DC, Auxiliary Power Unit Starting System, and Ground Service & Handling. This establishes the component selection and number of components. Once the architecture is selected, a default set of components and feeder layouts is automatically generated. These default selections can be altered and the changes locked-in by the user. Currently the method only redraws portions of some one-line diagrams (a future enhancement might extend this capability). If a radically different architecture is to be used, the user should select the closest default architecture as a starting point. It is then the user's responsibility to modify downstream screens with the appropriate type and number of components.

10 Generation

The method of sizing the generation line components relies upon data extracted from the Loads and Architecture modules. The Loads module dictates the required AC and DC load capacities and the Architecture module specifies the quantities of the various components. These data are used in sizing the various generation components. Figure 8 below shows the screen detailing the prime AC generators. If a variable frequency generator were used instead, the motor controller portion at the bottom of the screen would be populated.

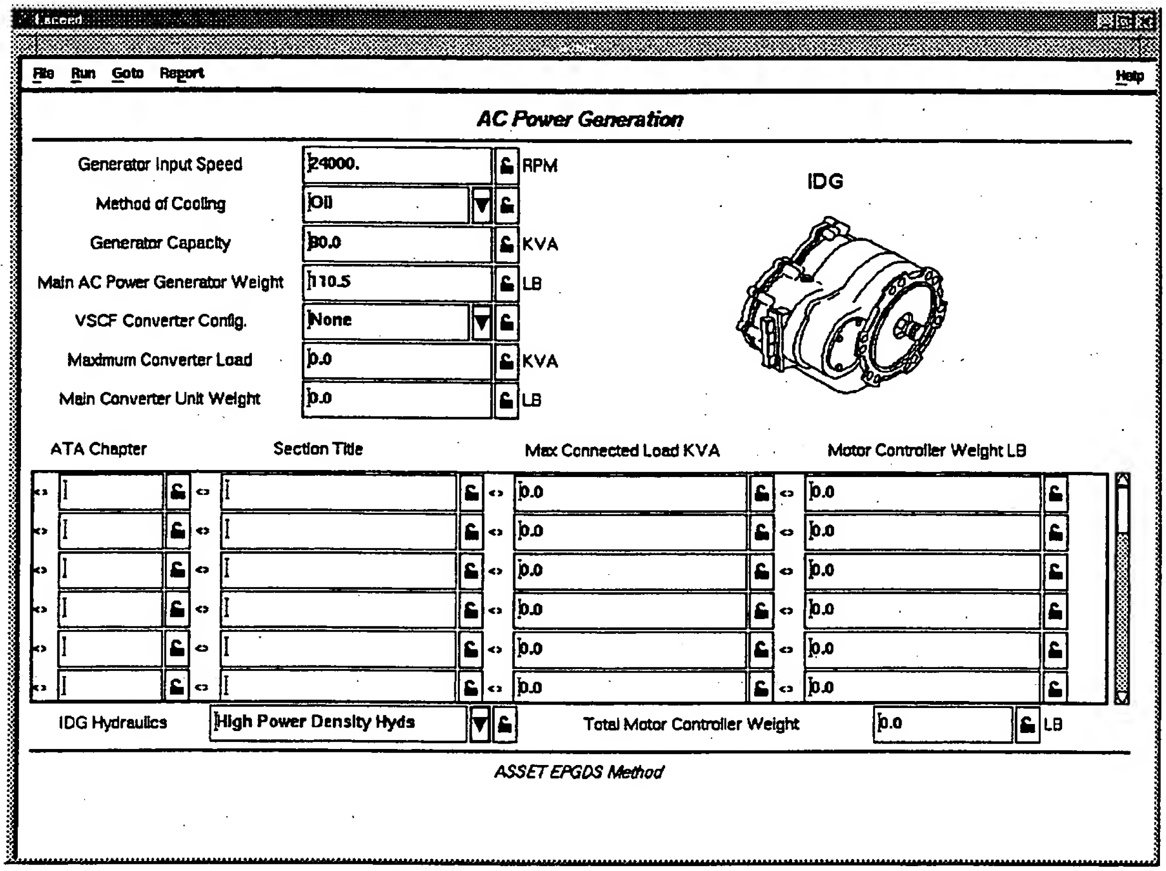

Figure 8: Typical Component Screen

Components whose weights are estimated by knowledge based engineering methods include the various generators, static inverter units, back up AC power generation units, transformer rectifier units, batteries, and battery chargers. Some of the smaller parts of the electrical system are estimated using walk away techniques from known components. The method calculates the smallest theoretical components that satisfy the electrical loads requirement.

An "as-built" switch (the default is on) substitutes the closest off-the-shelf component from a database. Typically a slightly higher capacity LRU is selected off-the-shelf than the theoretical calculation indicates is appropriate. Using off-the-shelf components is desirable due to the development time and cost associated with custom components.

11 Distribution

Standard power feeder wires between the prime generators or auxiliary power units and the main power panel location are selected autonomously. Feeder material, routing, and gauges are also determined by the method. The user has the usual option of overriding these selections. Figure 9 below shows a typical feeder layout with possible selections.

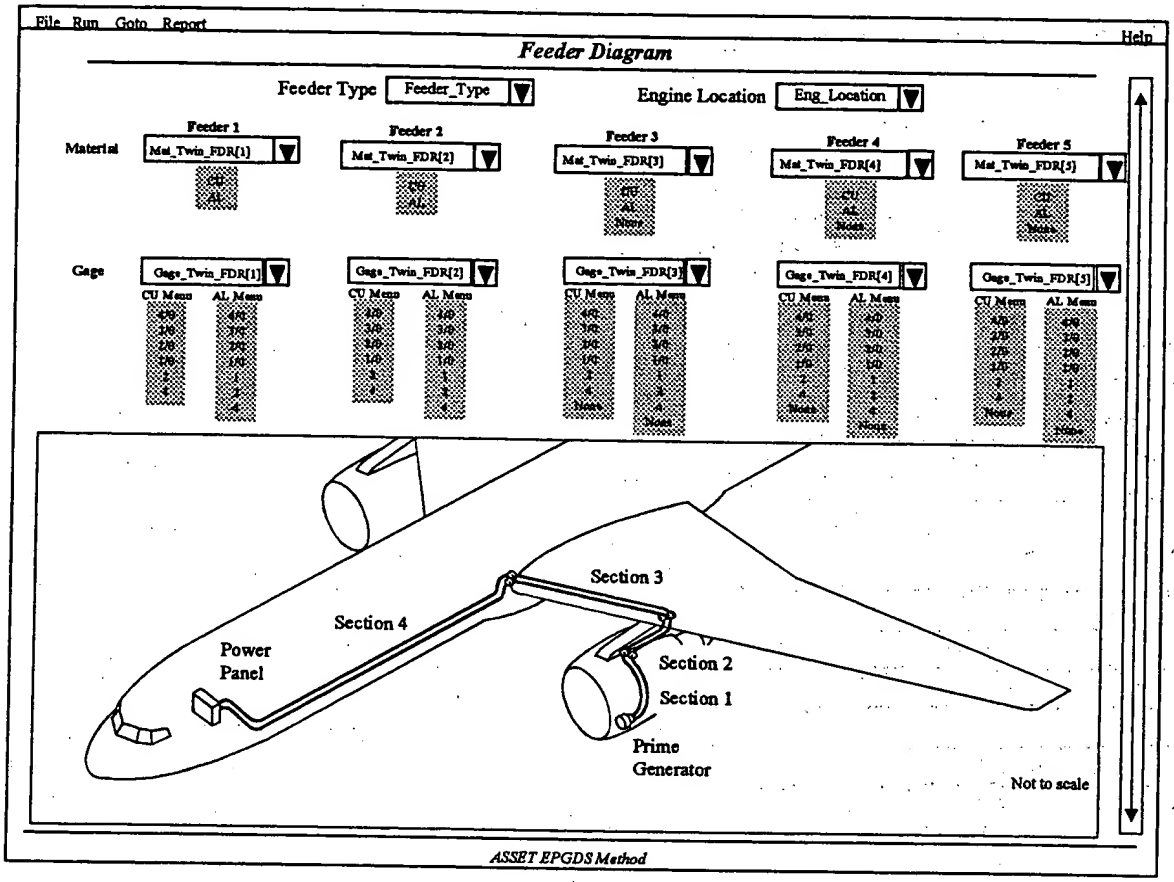

Figure 9: Typical Feeder Diagram

A simplified impedance calculation includes non-linear frequency effects and the effects of temperature, altitude, and feeder bundle physical arrangement. Electro-magnetic field analysis determined the frequency effects on current distribution within the feeders. Curve fits of resistance and reactance, as a function of frequency, were used to simplify the method (based on complex electro-magnetic field analysis using EMAS). These simplified curve fit equations gave results with excellent correlation to the more complex analysis.

It is important to use the lightest feeders possible that do not lose structural integrity due to heating effects. Influences include the ambient temperature of the region the feeder passes through, sizing altitude (a pressurization function), phase current, and feeder DC resistance. The feeder voltage drop calculation considers the skin proximity effect. This helps determine if unacceptable levels of wave form distortion and power loss is present.

12 Reliability

Reliability estimation is an important consideration in any system. The reliability, maintainability, and dependability cost attributes were limited to considering the impact of using a constant or variable frequency system. In-service historical data was analyzed to provide mean time between failures and other needed numerical parameters. These inputs are autonomously fed to an existing integrated reliability analysis program. In this way a mature reliability engine is utilized.

Any of the following conditions; loss of all AC, loss of all DC and loss of flight control DC compromises aircraft safety. The probability of occurrence of each of these conditions is calculated for the design under consideration. This permits the user to assess its flight safety. A fault tree is constructed and solved for each condition. The fault tree calculation considers flight length, failure rates and probabilities associated with components affecting the availability of the various power sources. A reliability input screen provides default inputs necessary for the reliability calculations. Output screens for main (see Figure 10 below), backup, and standby power are provided.

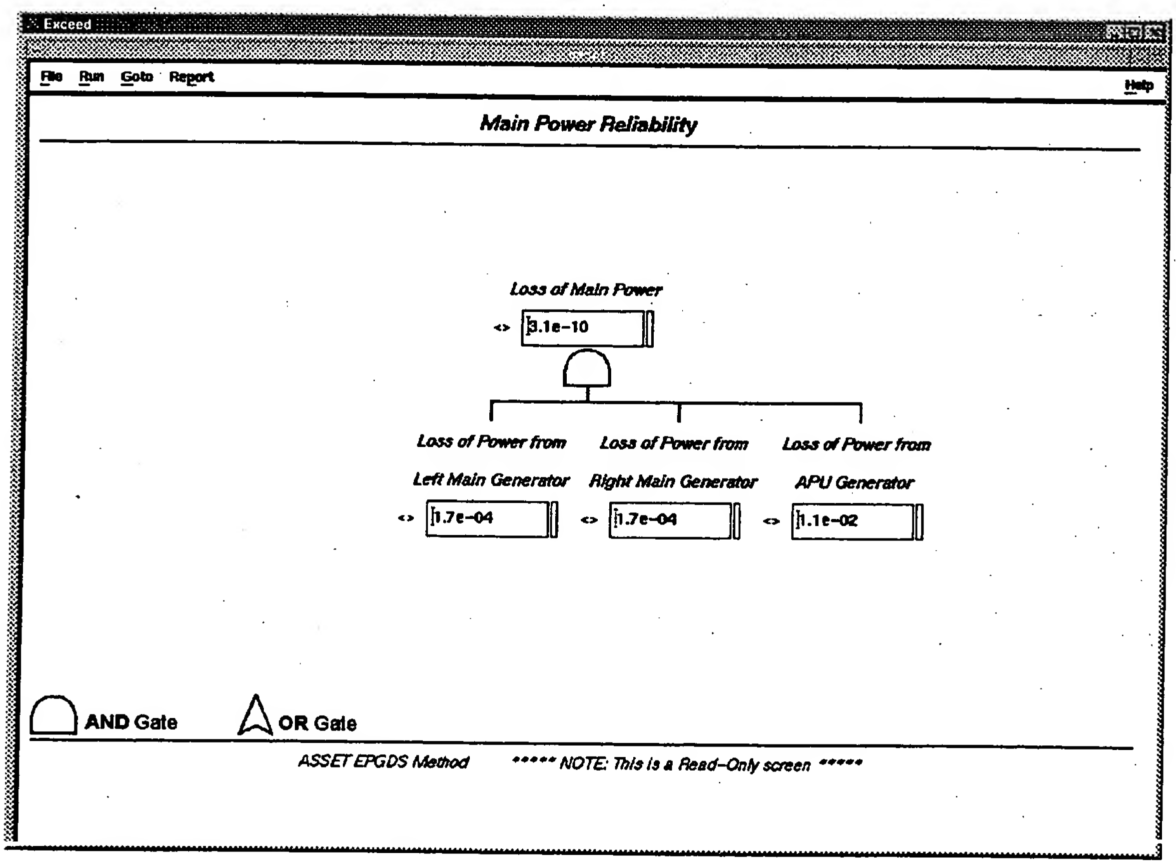

Figure 10: Typical Fault Tree

13 Maintainability

The system maintainability parameters are estimated. Inherent availability is a measure of the percent of time an aircraft is available for revenue service when unscheduled removals, servicing, alignment, and adjustment of the electrical system is considered. Inherent availability is calculated based on the elements shown in the summary screen of Figure 11 below. The first four terms on the screen below are developed on separate, earlier screens in this module. Components should be replaceable to factory specifications in a reasonable length of time. Good maintainability numbers reduces out of service time.

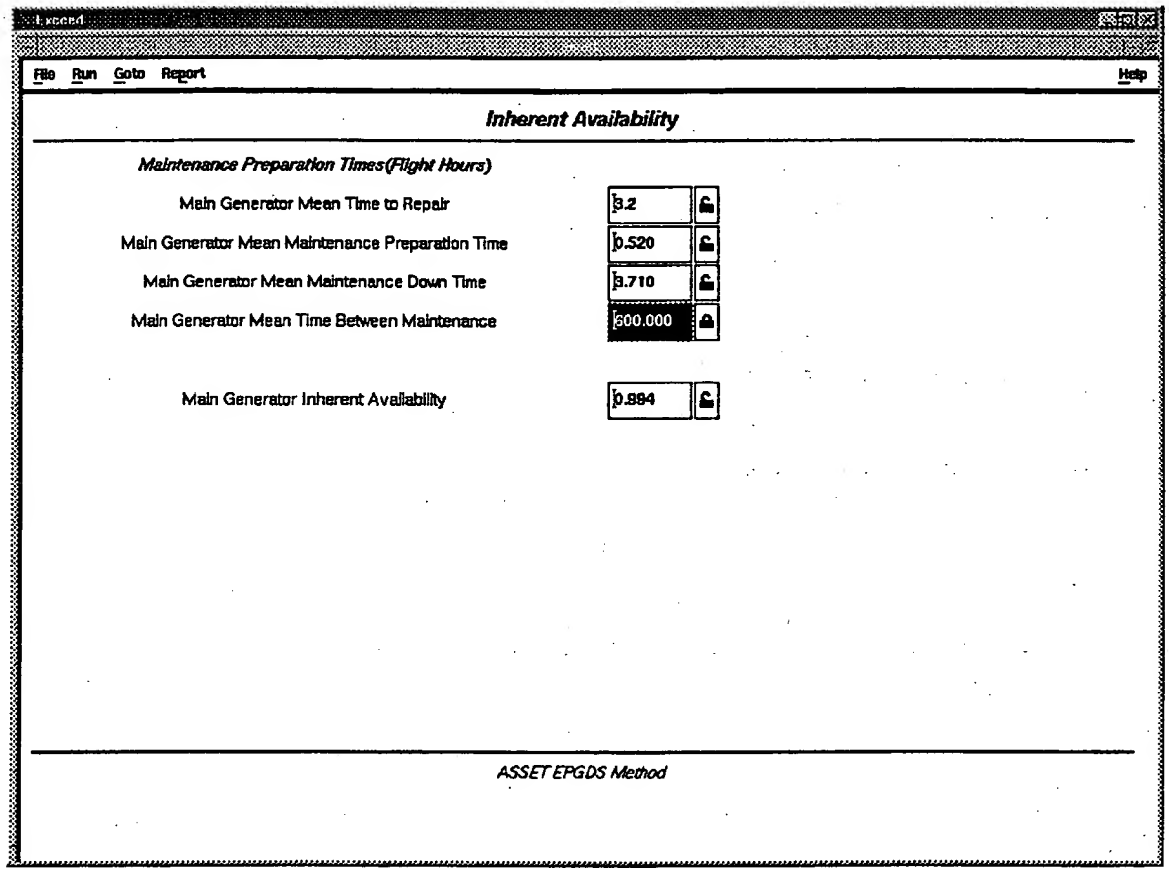

Figure 11: Maintainability Screen

14 Dependability Cost

The dependability cost estimation provides a useful measure of how much generator choice will cost an airline over the lifetime of an airplane. This is a quantitative assessment of how choice of the frequency type, constant or variable, impacts an airplane's ability to meet schedules, keep maintenance costs low, and be easily and quickly restored when a failure occurs. There are five elements of dependability cost. These are line maintenance cost, shop maintenance cost, schedule reliability cost, scheduled maintenance cost, and spares cost.

The cost of replacing a component and the frequency of its replacement are considered. Dependability cost is as important as the initial acquisition cost of the component or system, when calculated over the typical aircraft's life.

15 Body Station Center of Gravity

Body station refers to the longitudinal dimension from the nose or other pre-determined point of the aircraft to the tip of the tail. The center of gravity of each component along this axis is estimated and paired with the associated weight. These estimates are then combined to give an overall body station center of gravity for the electrical power generation and distribution system.

16 Mass Properties

Weight and body station center of gravity data are placed in three formats for various user groups; electrical, weights, and propulsion. These detailed, computer generated reports use the standardized layouts developed by those groups. These reports are automatically reconfigured depending on the aircraft configuration, architecture and component selection that was made. This gives the using engineer a formatted weight and body station center of gravity summary.

17 Summary

The electrical system method described demonstrates that multiple attributes other than mass properties can be economically included with a weight estimation method. It provides a quick way to assess multiple measures of the worth of an electrical system under consideration, automatically, without additional detailed analysis on the weight engineer's part. It allows quick trades between alternative systems in a preliminary design environment, while allowing a seamless transition to detailed design accuracy through the use of overrides as concrete knowledge of the system is gained. It supports electrical power generation and distribution system engineering trade studies.

18 Biography

The author has worked as an electrical, electromagnetics, control system, and attitude determination engineer. He has been with Boeing for about nineteen years. For the last seven years Bob has worked in aircraft weights research in Renton, Washington. He holds a BS and MS in Electrical Engineering, and a MBA degree. Bob is a professional engineer in the Electrical Engineering discipline. He is a Senior Member of SAWE. Bob is the current Vice President of the Seattle Chapter of SAWE.

19. Bibliography

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To: Lawrence W. Nelson 13-08

Subject:: Boeing Invention Disclosure No. 01-157, "ASSET Electrical Power Generation and Distribution System Method"

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*************ADDITIONAL INFORMATION (if known and appropriate)************

1. Actual or projected date of first use by Boeing or others:

30 October 2000

2. Actual or projected date of publication (outside of Boeing) of concepts or other information relating to the invention:

21 May 2001

3. Useful descriptive materials (documents, drawings, test results, etc.);

(1) SAWE Paper: "Electrical Power Generation and Distribution System Estimation". (2) SAWE Presentation Slides.

______ Copy included X Will furnish upon request

25 April 2001
(Date)

Robert M. Bond
(Signature)

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